Remanent magnetization of high-temperature Josephson junction arrays

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Abstract

In this work we study the remanent magnetization exhibited by tridimensional disordered high-T_c Josephson junction arrays excited by an AC magnetic field. The effect, as predicted by numerical simulations and previously verified for a low-T_c array of Nb, occurs in a limited range of temperatures. We also show that the magnetized state can be excited and detected by two alternative experimental routines.

In a recent work[1] we have demonstrated that Josephson junction arrays (JJAs) fabricated from granular Nb may exhibit a magnetic remanence, M_r, upon excitation by a magnetic field. As predicted[2], the magnetized state occurs in a window of temperatures, whose extent depends on the critical current, J_c, of the junctions. Also, there is a threshold value for the magnetic field in order to drive the JJA to the state where flux is retained after suppression of the field[1,2]. In Ref. 1 we have also shown that the profile of M_r is sensitive to the critical current dispersion, what stresses the prospective use if this effect as a suitable tool for determining the critical current distribution of the array, $N(J_c)$.

This contribution presents selected parts of a systematic study of the remanent magnetization displayed by our newly produced high-temperature tridimensional disordered arrays (3D-DJJAs), fabricated from granular $YBa_2Cu_3O_{7-\delta}$. The experimental results confirm the predictions, revealing that the remanence develops in a limited range of temperature.

Granular YBCO material used to fabricate the arrays was prepared employing a modified method of polymeric precursors[3]. This route consists of mixing oxides and carbonates in stoichiometric amounts dissolved in HNO_3, and then to an aqueous citric acid solution. A metallic citrate solution is then formed, to which ethylene glycol is added, resulting in a blue solution which was neutralized to pH~7 with ethylenediamine. This solution was turned into a gel and subsequently decomposed to a solid by heating at 400 ^{o}C. The sample was heat-treated at 850 ^{o}C for 12 h in air with several intermediary grindings, in order to prevent undesirable phase formations. Then, it was pressed into a pellet using controlled uniaxial (5,000 kgf/cm^2) pressure and sintered at 950 ^{o}C for 6 h in O_2. This pellet is a 3D-DJJA, in which the junctions are weakly coupled grains, i.e., weak-links (WLs) formed by a sandwich of YBCO grains and intergrain material. As a consequence of the uniaxial pressure, samples produced in this way are anisotropic, a feature that can be either enhanced, by using higher pressures, or reduced, by applying isostatic pressures. Also, thermal treatment plays a fundamental role on creation and control of WLs and anisotropy, as will be thoroughly discussed elsewhere[4].

The sample studied here exhibits all characteristic features of a genuine 3D-JJA, the most significant of which are shown in Fig.1: the main picture is a low-field measurement of a positive magnetization[5] (Wohlleben Effect), for $H = 0.02\ Oe$. The inset displays a Fraunhofer pattern for the real part of the magnetic susceptibility χ_{AC}. As demonstrated in Ref. 6, this is an indirect determination of J_c.

To study the remanent state of the arrays, we employ two routines especially developed for detection and study of granular JJAs: the Temperature Scan Routine (TS) and the Field Scan Routine (FS). The core of both experimental procedures consists of two steps:

i. the sample is submitted to an AC field (h) consisting of a train of sinusoidal pulses, after what h is kept null;

ii. with $h = 0$, the magnetic moment of the sample is measured.

In the FS routine we measure $\chi_{AC}(h)$ performing steps (i) and (ii) as h is varied at a fixed temperature. On the other hand, the TS routine is employed to measure, at a

fixed value of h, $\chi_{AC}(T)$ through steps (i) and (ii). All measurements were performed using a Quantum Design MPMS-5T SQUID magnetometer. Both routines were extensively explored, furnishing valuable results for the purposes of this work. In this short paper, however, we emphasize the similarities among results obtained employing the two alternative routines. Remaining parts of this study, including many other aspects of the problem, will be published elsewhere.

As expected, the high-T_c disordered array studied here, a heat-treated isotropic 3D-DJJA of YBCO, exhibits the predicted magnetic behavior. The magnetized state at zero field can be easily recognized from measurements using either one of the above mentioned routines. Remanence versus temperature curves normalized to peak values, are shown in Fig.2. The main graph represents a direct measurement of $M_r(T)$ on warming, employing the TS routine. Intragranular contributions were not subtracted from this curve, but are totally irrelevant, as we have certified by measuring unlinked grained material, for which no magnetic remanence was detected. As in the case of the Nb array reported previously[1], the remanence is intense for a limited temperature interval. In the present case, the temperature window for which the array is magnetically active has a quite long low-T tail, revealing that $N(J_c)$ is broad. It should be noticed that the magnetic response ceases at $T^* = 83\ K$, a temperature significantly smaller than $T_c = 90\ K$. The inset shows a few representative points of an experiment performed using the FS routine for $h_o = 10\ mOe$. The AC field was cycled up to 3.8 Oe and then down to zero, after which values of ΔM_r were calculated by subtraction between $M_r(h_o)$ increasing and decreasing h. The curve obtained is a replica of that measured directly using the TS routine.

In conclusion, we have measured the predicted magnetic remanence of JJAs, using a 3D-DJJA fabricated from granular YBCO. The remanence is intense within a limited interval of temperatures. The $M_r(T)$ profile, which is sensitive to the critical current dispersion, reveals a fairly broad $N(J_c)$ for the array.

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5. Throughout the paper, M is the volume magnetization, i.e., the magnetic moment of the samples.

6. P. Barbara et al., Phys. Rev. B 60 (1999) 7489.

FIGURES

Fig. 1.   Positive magnetization (Wohlleben Effect) of a 3D-JJA of YBCO, measured on cooling at $H = 30mOe$. Inset shows the Fraunhofer pattern of χ_{AC} for the sample.

Fig. 2.   Magnetic remanence exhibited by a 3D-DJJA of YBCO, as measured using the TS (main graph) and the FS (inset) routines.